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United States Patent [19]

Fahimi et al.

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[45] **Date of Patent: Sep. 19, 2000**

[54] **NEGATIVE PRESSURE HEAD CONTOUR IN A LINEAR TAPE RECORDING SYSTEM WITH TAPE DEFORMING CAVITY**

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[73] Assignee: **Imation Corp.**, Oakdale, Minn.

[21] Appl. No.: **09/225,281**

[22] Filed: **Jan. 5, 1999**

[51] **Int. Cl.**[7] **G11B 15/60**

[52] **U.S. Cl.** **360/221**; 360/130.21

[58] **Field of Search** 360/221, 130.21

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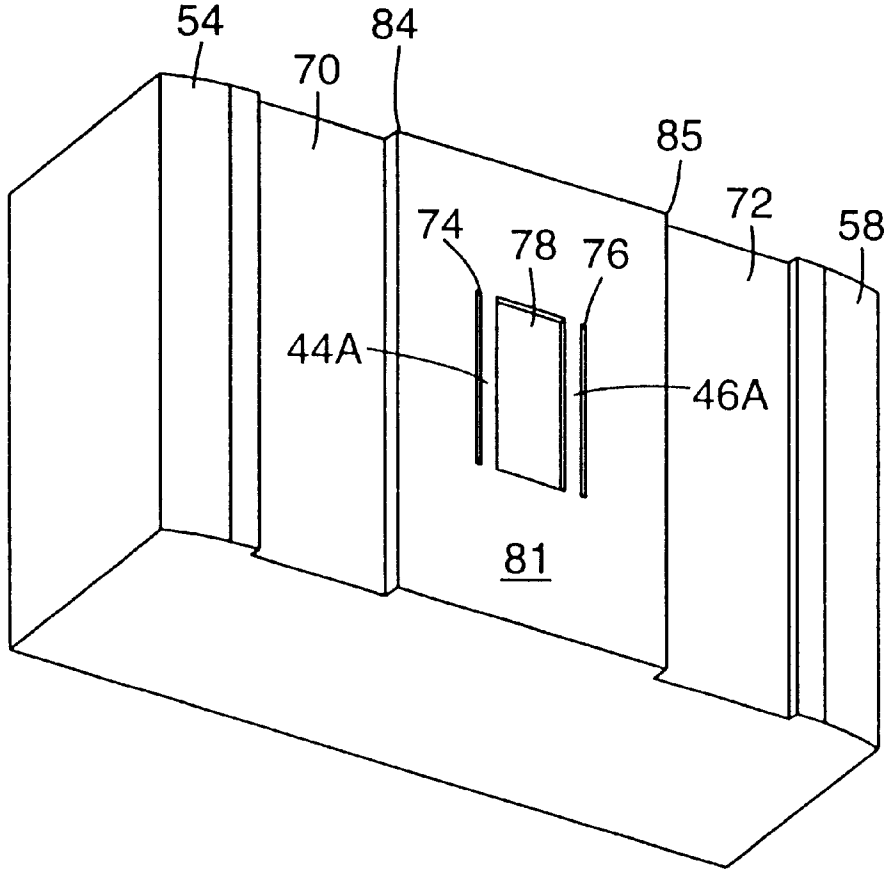
Primary Examiner—A. J. Heinz

Attorney, Agent, or Firm—Eric D. Levinson

[57] **ABSTRACT**

A magnetic head assembly in a linear tape system having an interface region having a substantially flat region with a substantially square leading edge and at least one cavity in the flat region. The cavity has a depth of about 0.5 micrometers to about 20 micrometers. At least one read-write element is located on the flat region adjacent to the cavity. As a magnetic tape traversing the interface region, a sub-ambient condition is generated. The magnetic tape is bent or otherwise deformed as it passes over the cavity, thereby increase tape stability at the interface with the read-write elements. A magnetic tape system for recording, reproducing and/or erasing magnetic information in a linear tape system or for servo-writing magnetic tapes is also disclosed.

25 Claims, 12 Drawing Sheets



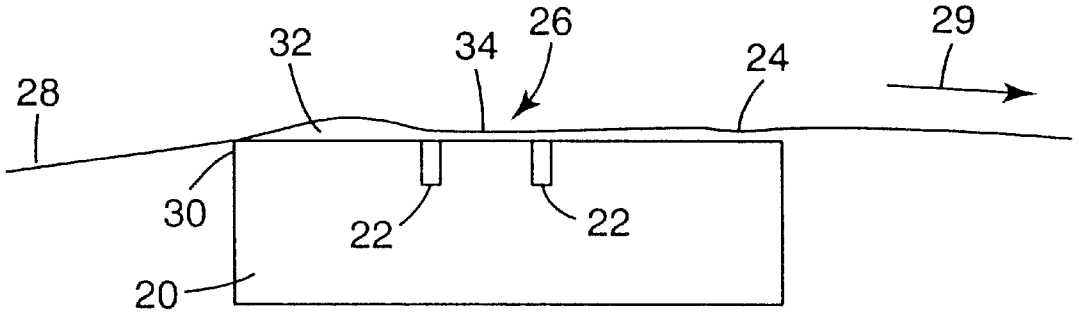


Fig. 1A
PRIOR ART

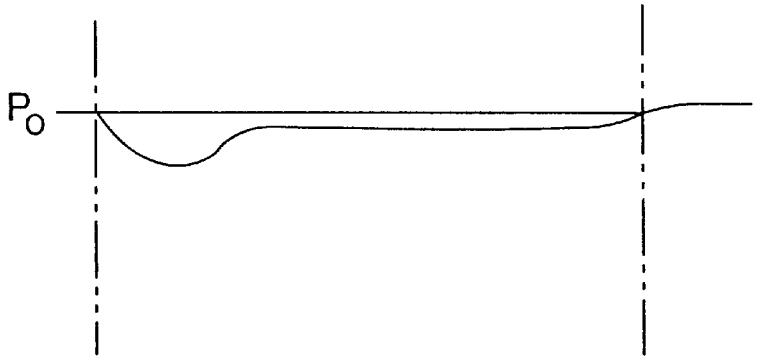


Fig. 1B
PRIOR ART

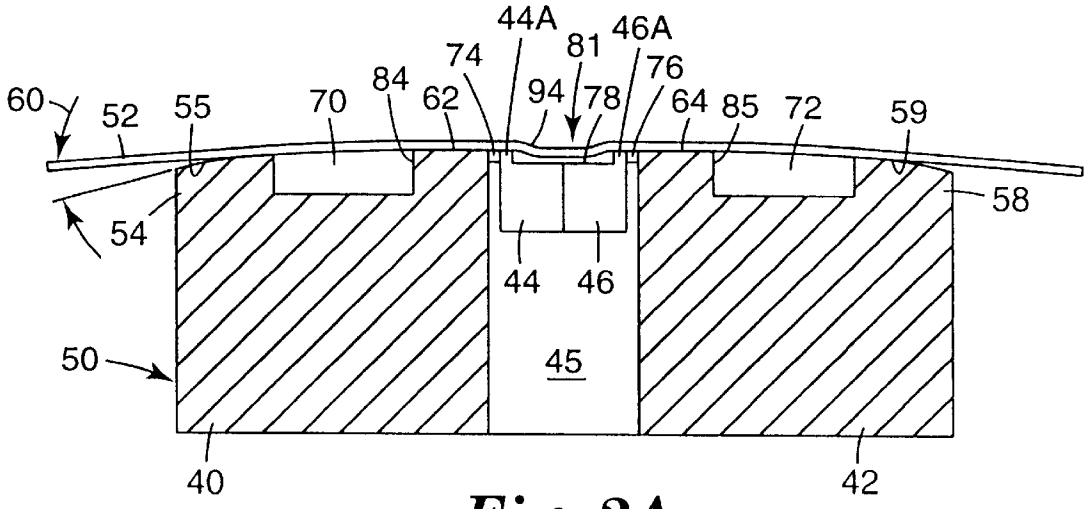


Fig. 2A

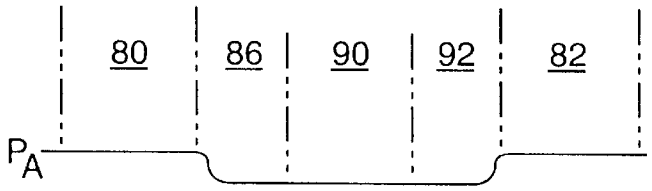


Fig. 2B

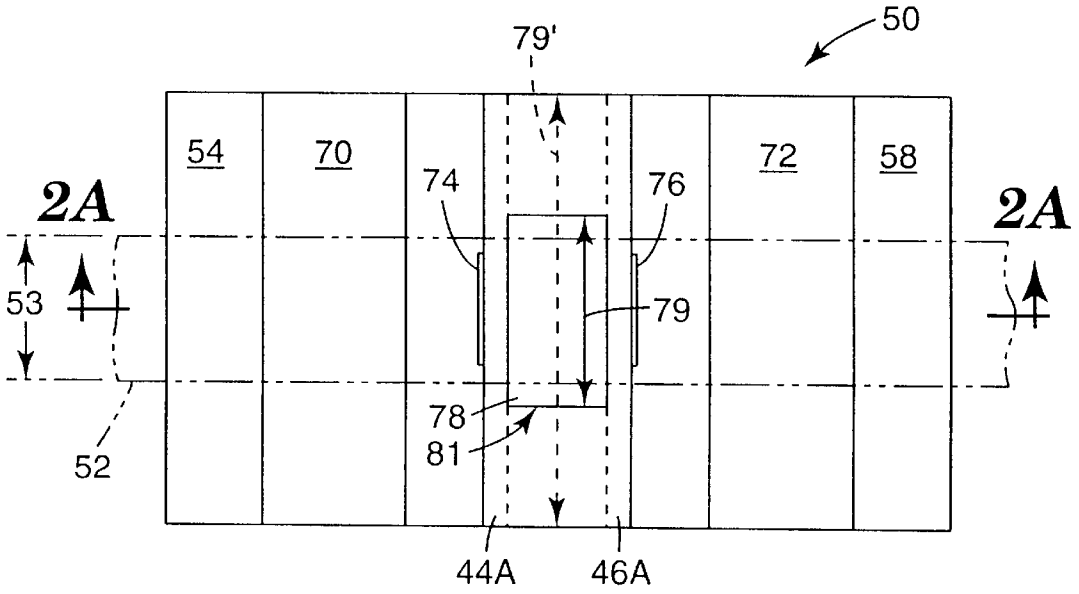


Fig. 3

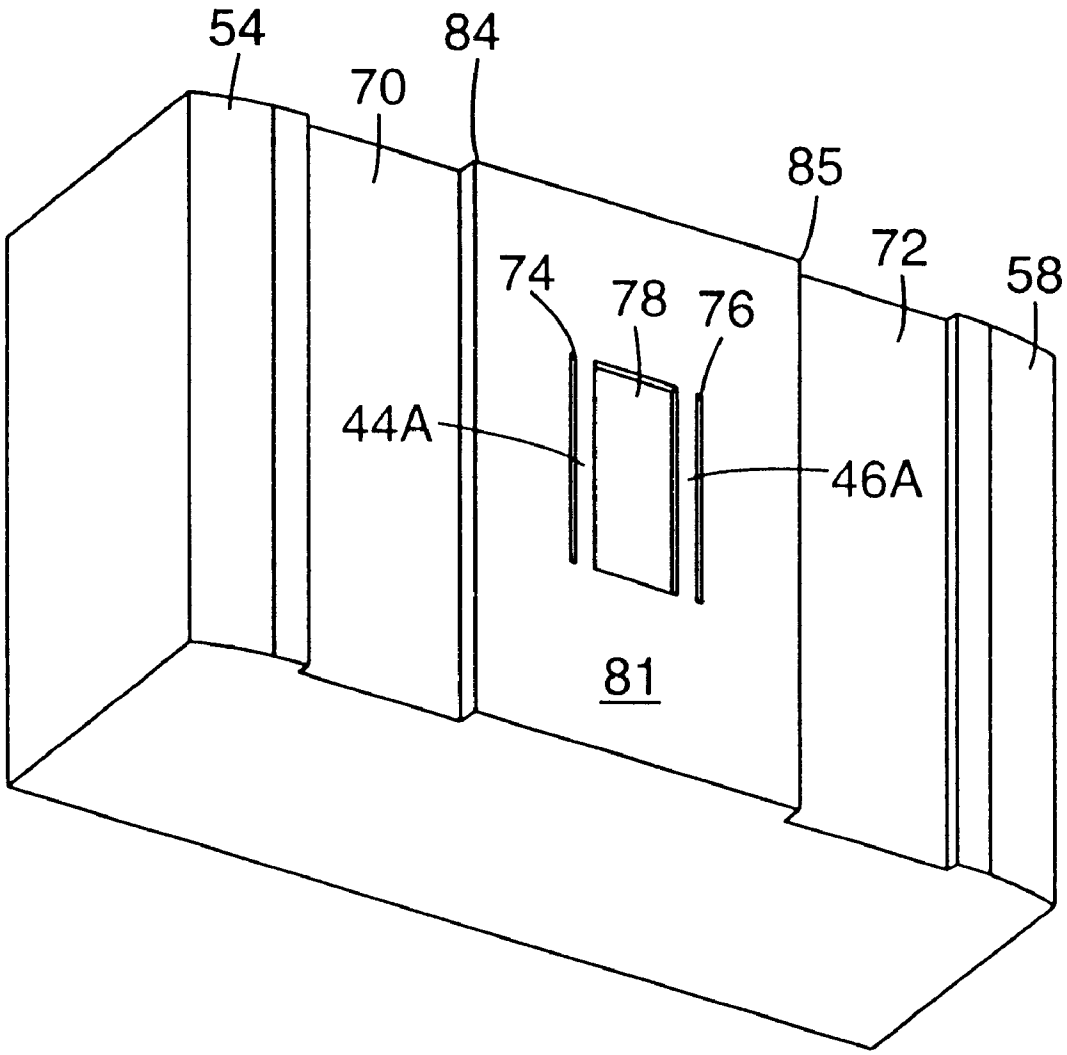
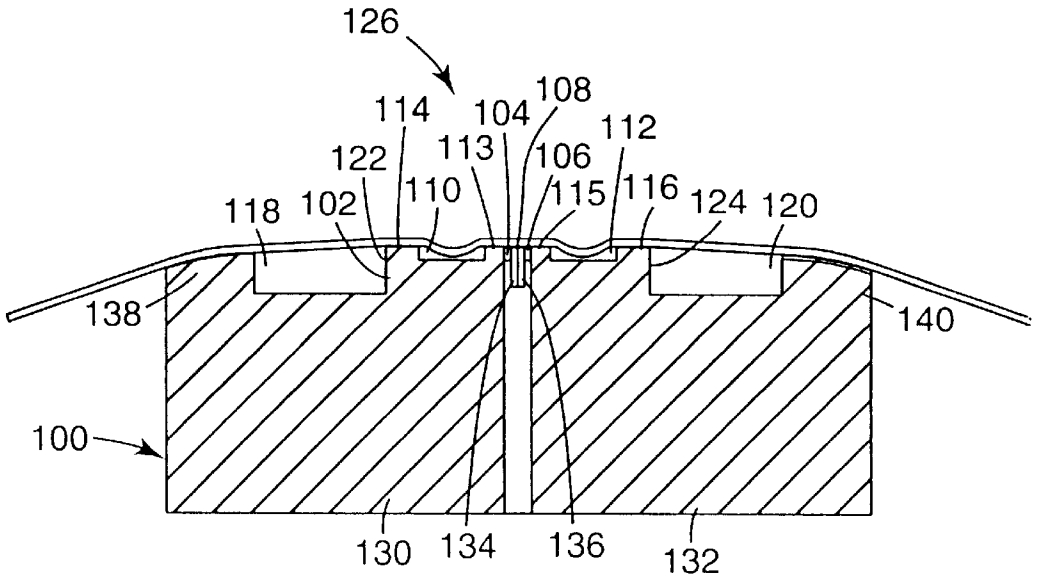


Fig. 4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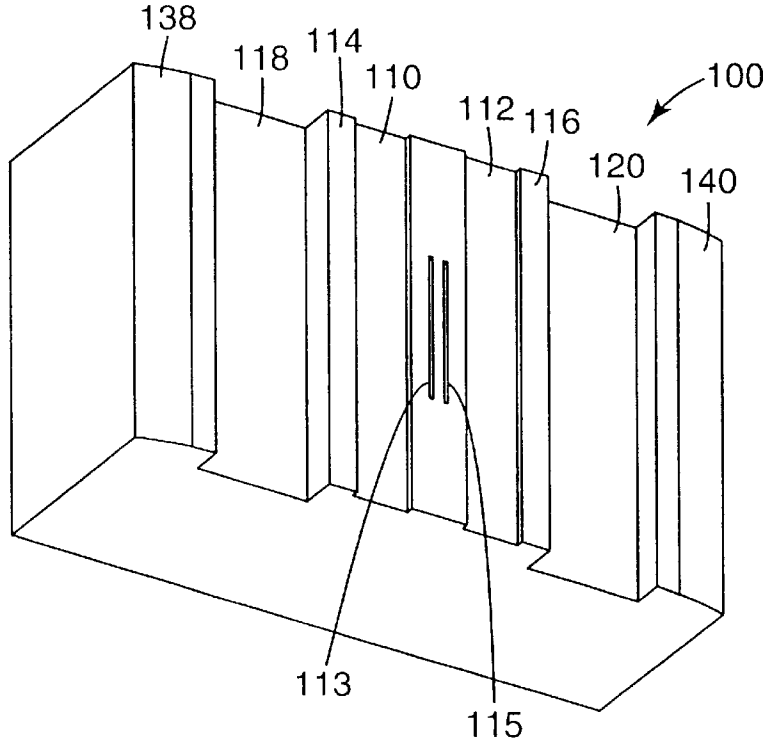
114
104
108
112
122
113
106
118
102
110
115
116
124
120
138
140
100
130
134
136
132

Fig. 5A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118
114
110
112
116
100
120
140
113
115

Fig. 5B

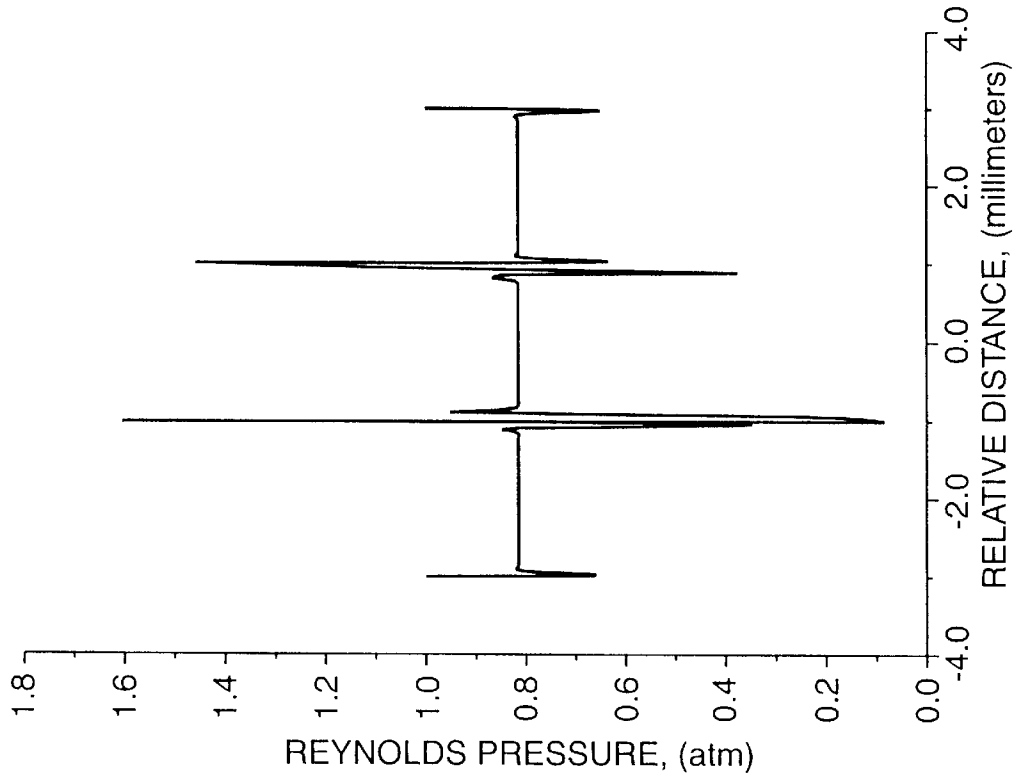
REYNOLDS PRESSURE, (atm)
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
RELATIVE DISTANCE, (millimeters)
4.0
2.0
0.0
-2.0
-4.0

Fig. 6B

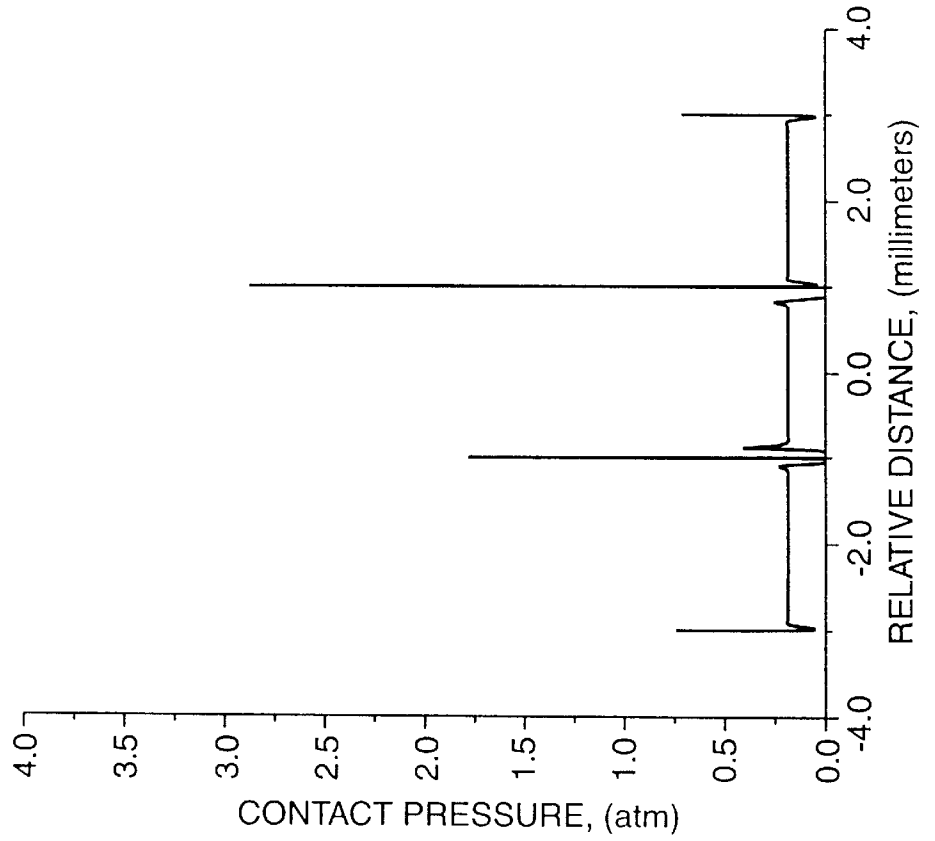
CONTACT PRESSURE, (atm)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
RELATIVE DISTANCE, (millimeters)
4.0
2.0
0.0
-2.0
-4.0

Fig. 6A

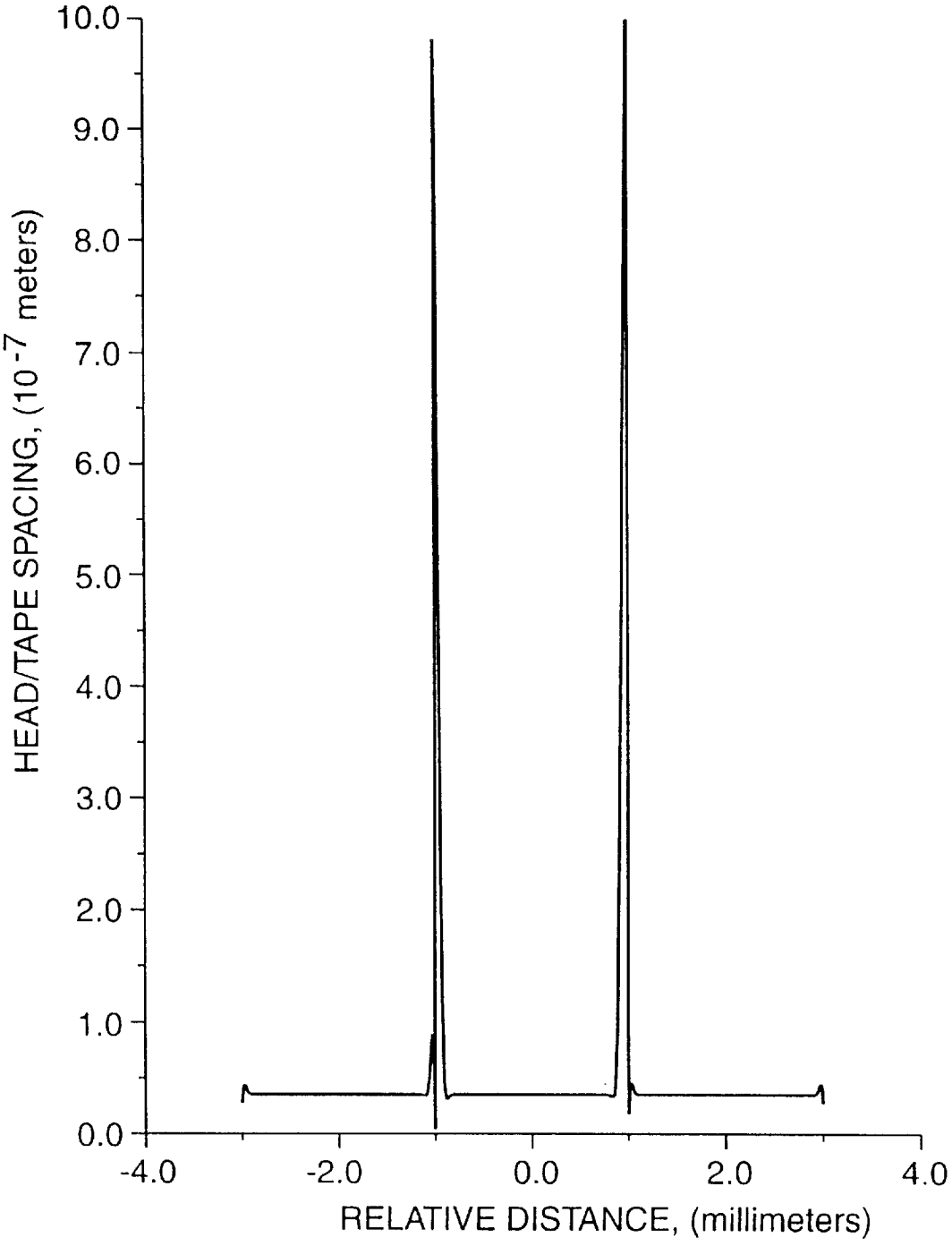
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
HEAD/TAPE SPACING, (10^{-7} meters)
-4.0
-2.0
0.0
2.0
4.0
RELATIVE DISTANCE, (millimeters)

Fig. 6C

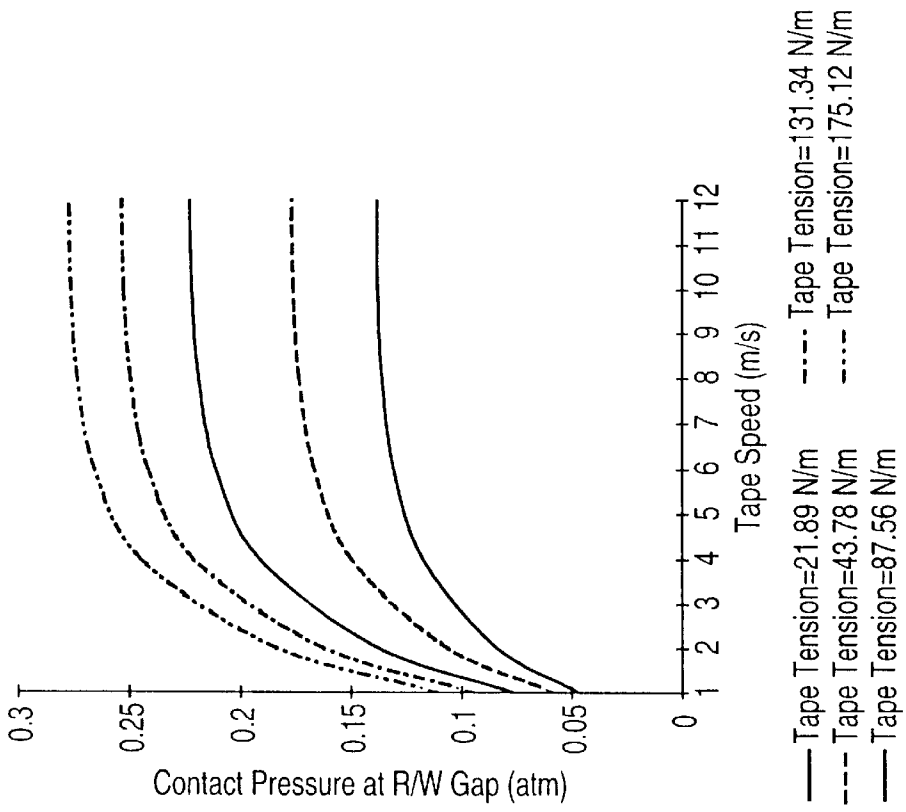
Contact Pressure at R/W Gap (atm)
0.3
0.25
0.2
0.15
0.1
0.05
0
1 2 3 4 5 6 7 8 9 10 11 12
Tape Speed (m/s)
Tape Tension=21.89 N/m
Tape Tension=43.78 N/m
Tape Tension=87.56 N/m
Tape Tension=131.34 N/m
Tape Tension=175.12 N/m

Fig. 8

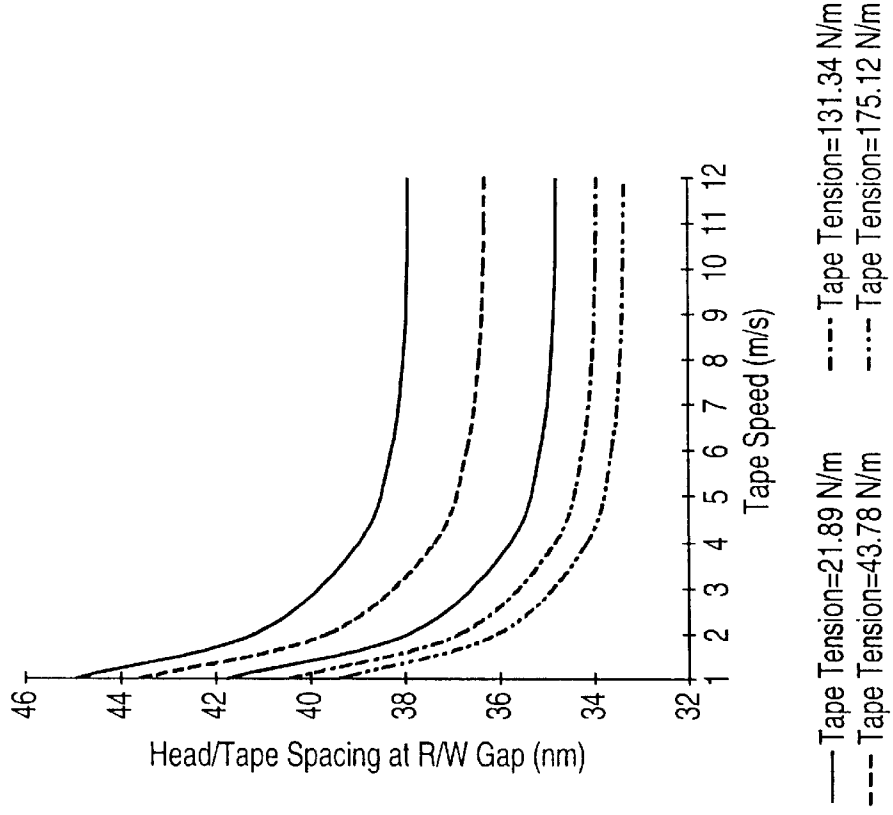
Head/Tape Spacing at R/W Gap (nm)
46
44
42
40
38
36
34
32
1 2 3 4 5 6 7 8 9 10 11 12
Tape Speed (m/s)
Tape Tension=21.89 N/m
Tape Tension=43.78 N/m
Tape Tension=87.56 N/m
Tape Tension=131.34 N/m
Tape Tension=175.12 N/m

Fig. 7

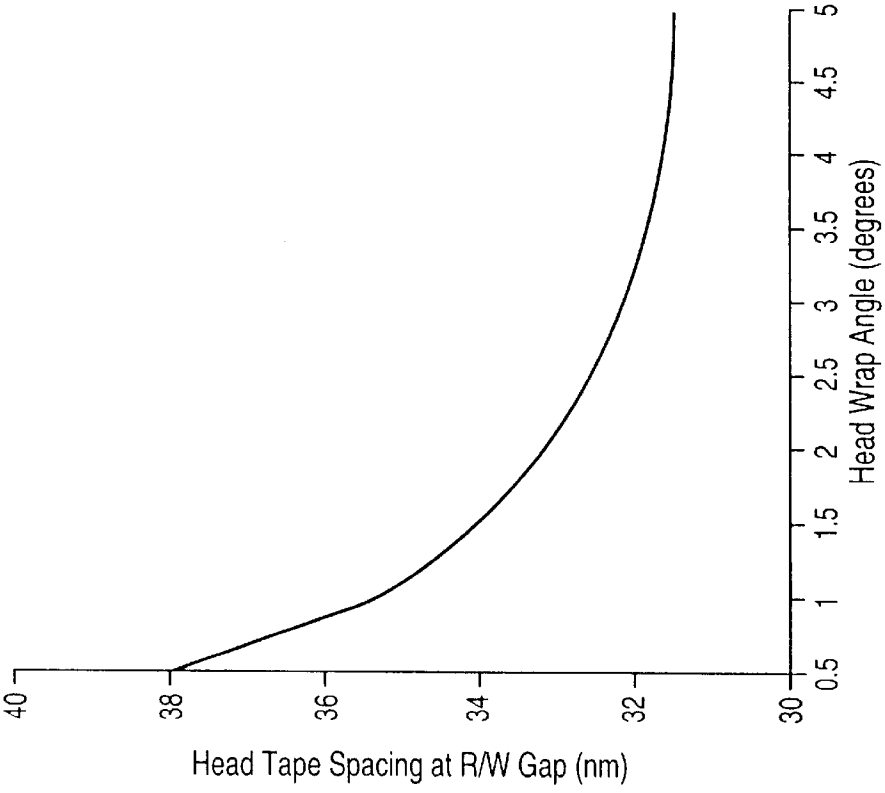
40
38
36
34
32
30
Head Tape Spacing at R/W Gap (nm)
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Head Wrap Angle (degrees)

Fig. 10

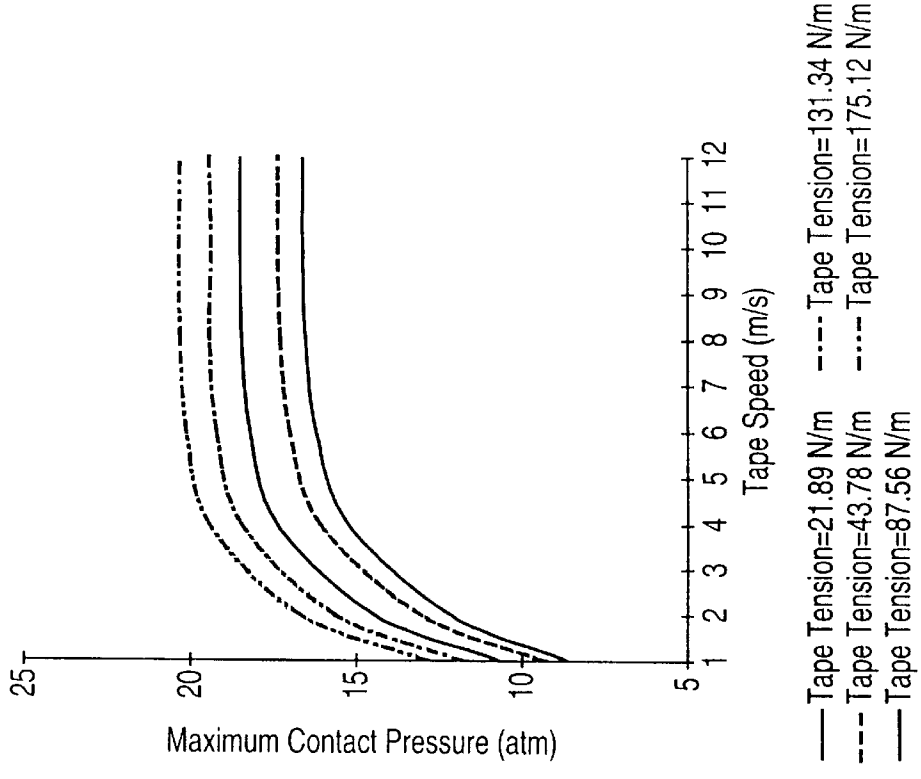
25
20
15
10
5
Maximum Contact Pressure (atm)
1 2 3 4 5 6 7 8 9 10 11 12
Tape Speed (m/s)
Tape Tension=21.89 N/m
Tape Tension=43.78 N/m
Tape Tension=87.56 N/m
Tape Tension=131.34 N/m
Tape Tension=175.12 N/m

Fig. 9

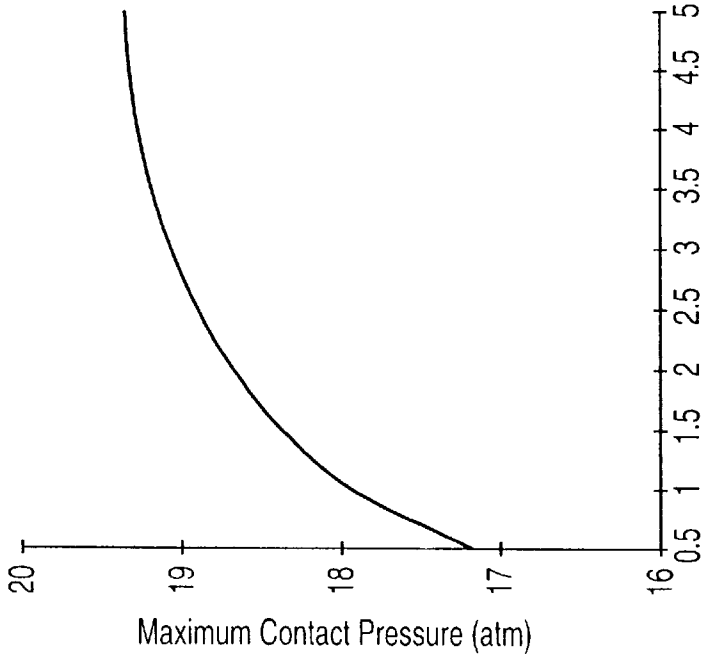
Maximum Contact Pressure (atm)
20
19
18
17
16
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Head Wrap Angle (degrees)

Fig. 12

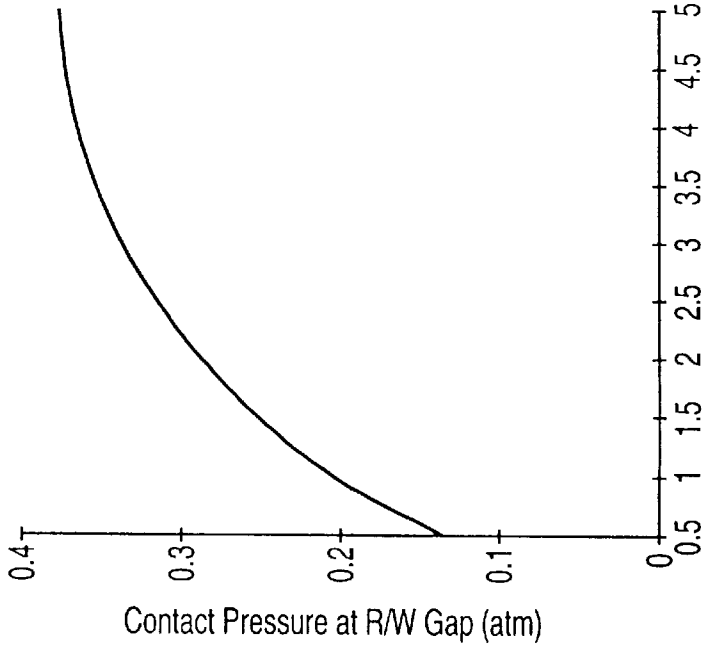
Contact Pressure at R/W Gap (atm)
0.4
0.3
0.2
0.1
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Head Wrap Angle (degrees)

Fig. 11

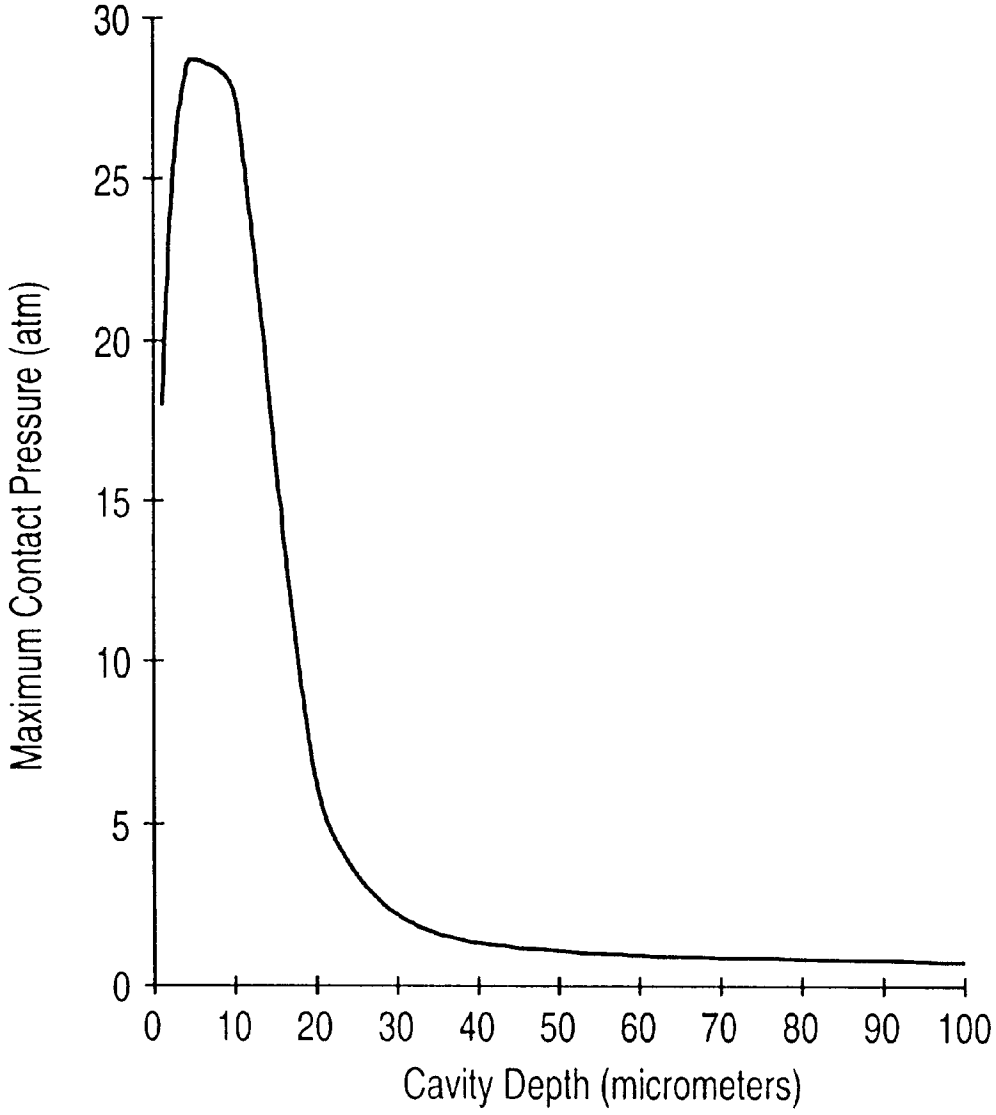
Maximum Contact Pressure (atm)
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
90
100
Cavity Depth (micrometers)

Fig. 13

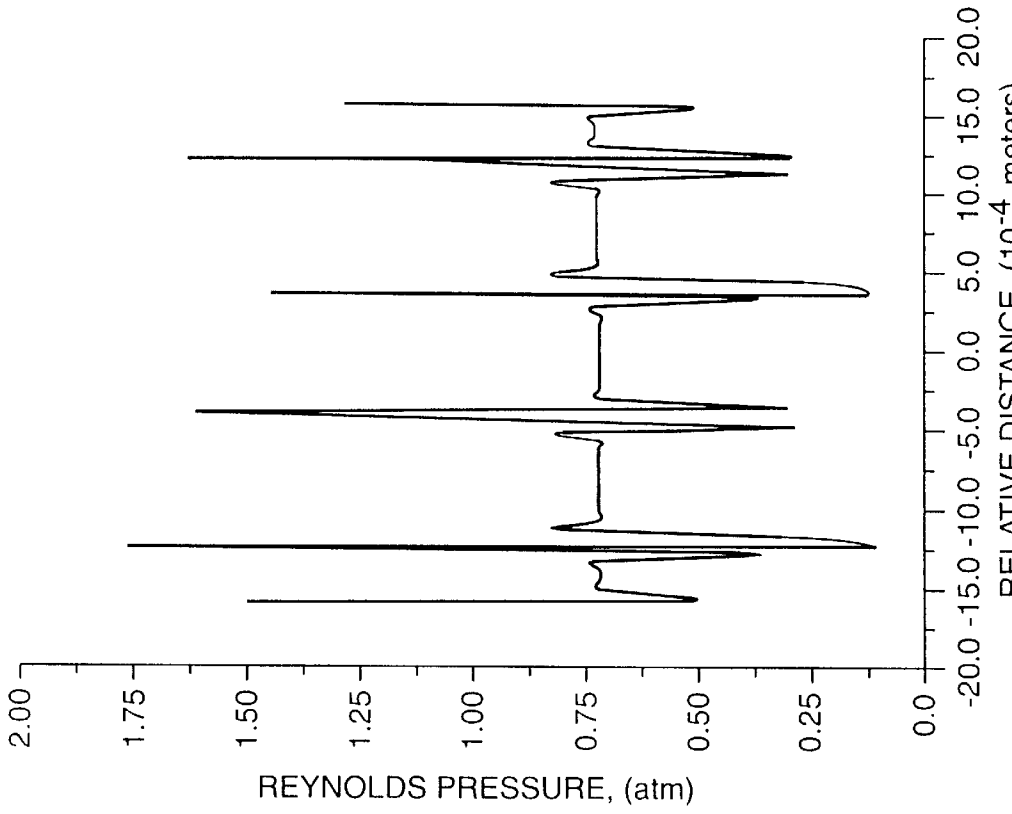

Fig. 14B

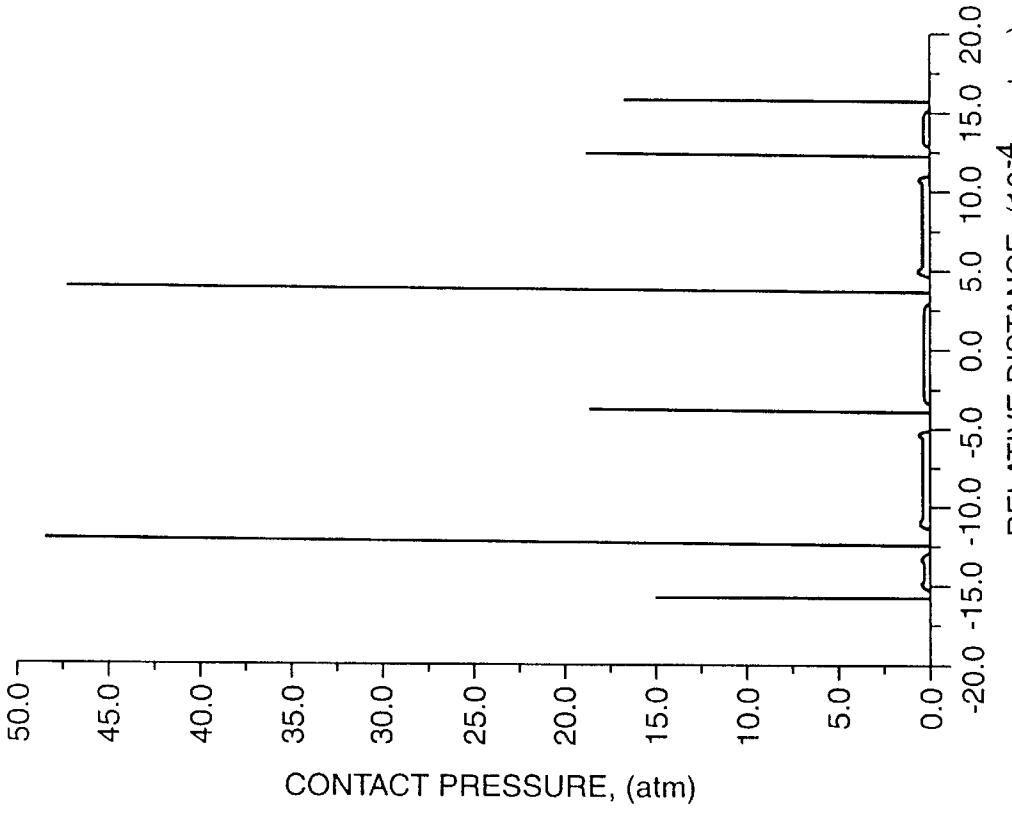

Fig. 14A

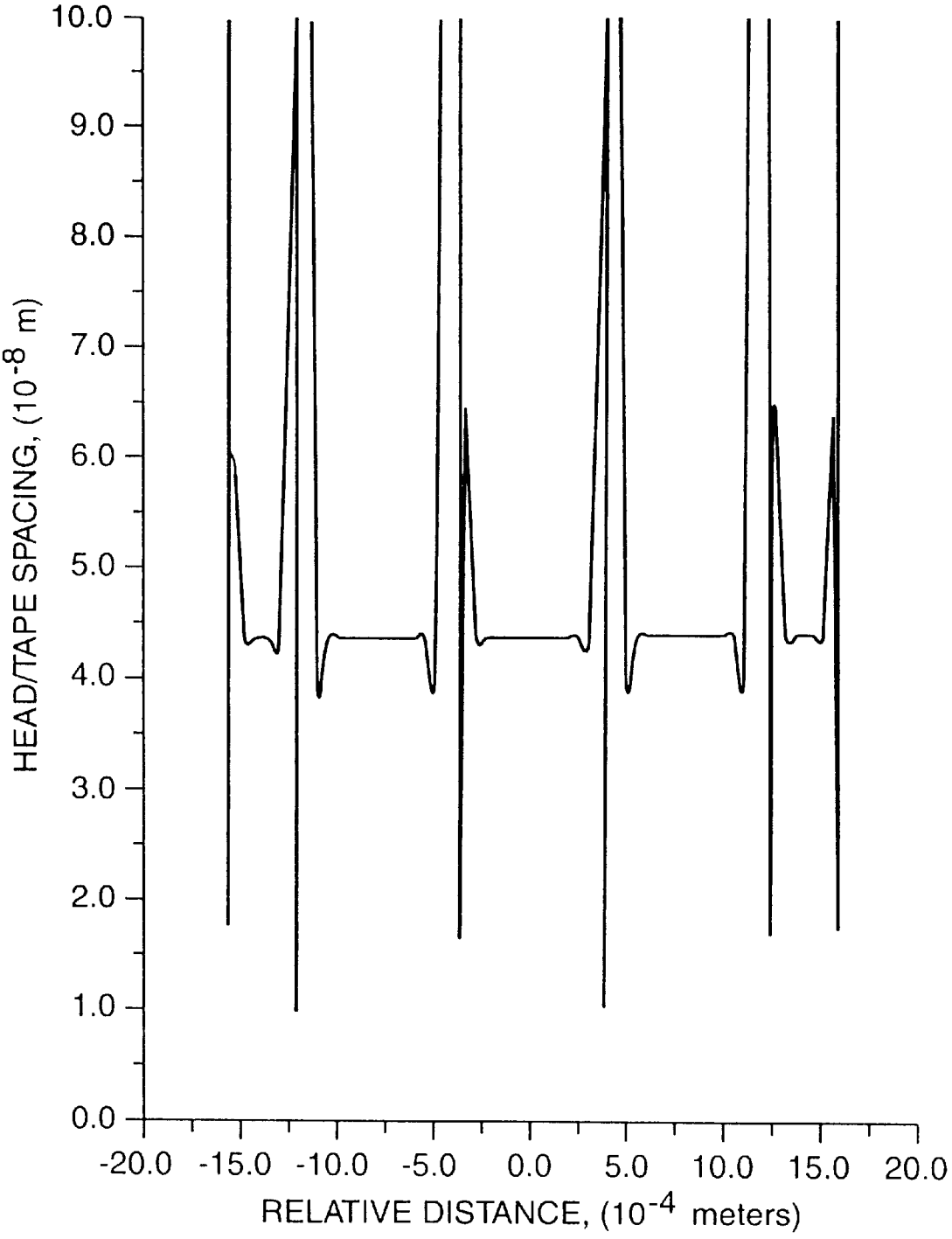
10.0
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
HEAD/TAPE SPACING, (10^{-8} m)
-20.0
-15.0
-10.0
-5.0
0.0
5.0
10.0
15.0
20.0
RELATIVE DISTANCE, (10^{-4} meters)

Fig. 14C

NEGATIVE PRESSURE HEAD CONTOUR IN A LINEAR TAPE RECORDING SYSTEM WITH TAPE DEFORMING CAVITY

This invention was made with Government support under the Cooperative Agreement No. 70NANB5H1 16 awarded by the National Institute of Standards and Technology (NIST). The Government has certain rights in this invention.

FIELD OF THE INVENTION

The present invention is directed to a magnetic head assembly for reading, reproducing and/or erasing magnetic information in a track of a flexible magnetic tape, and in particular, to a flat-top negative pressure head contour having a cavity that utilizes the bending force of the tape to achieve stable head-to-tape spacing.

BACKGROUND OF THE INVENTION

The trend in the magnetic recording art is toward higher capacity, higher transfer rate, faster access, and increased system bandwidth through the recording and playback of shorter and shorter wavelength signals. This trend necessitates intimate contact at the interface between the magnetic head and the recording medium.

In order to obtain optimum performance in writing to and reading from magnetic tape, it is necessary that the moving tape be kept in close and stable proximity to the magnetic head. As the head-to-tape separation or flying height increases, performance deteriorates. The primary consequences of a higher tape flying height are a decrease in read amplitude and an upward shift in the peak write current. Conversely, the read amplitude increases as the flying height decreases. Therefore, an increase in tape head performance can be obtained by minimizing flying height.

The magnetic head contour is typically cylindrical. At higher tape speeds, an air layer adherent to the moving tape becomes entrained between the magnetic head and the tape surface traversing the head, causing the magnetic tape to "fly" over the head. The entrained air acts as an air bearing, lifting the tape from the head contour and separating the recording medium from the interface, with resultant signal degradation.

Intimate contact between the tape and the magnetic head at the interface is typically increased by a combination of greater tape tension across the magnetic head and more penetration of the magnetic head into the tape. Another approach to minimizing flying height on cylindrical magnetic heads is to incorporate bleed slots. Bleed slots are grooves in the contour surface. As the tape moves across the head, the bleed slots help to channel entrained air away from the head-to-tape interface, thus reducing the height distribution of the layer of air. Thus, bleed slots function in a manner that is analogous to treads on a tire. Just as the tire treads help to channel water away from the tire surface to prevent hydroplaning, bleed slots help to channel away air from the head contour surface to minimize head-to-tape separation.

An optimized head contour design is typically based on a cylindrical surface having a radius of curvature of about 4 to about 8 millimeters and air bleed grooves, either longitudinally or transversally, to maintain minimal head-to-tape spacing. In a typical head-to-tape interface, head-to-tape penetration of about 3 to about 5 millimeters in combination with about 80 to about 120 Newtons per meter of tape tension to create adequate downward force to achieve close

head-to-tape spacing. However, these conditions can lead to increased head wear and tape damage. Excessive wear may result in either alterations of the head profile or erosion of the gap in the case of thin film heads.

For example, after prolonged usage, an undulating wear profile is typically created on the magnetic head in a direction perpendicular to the motion of the magnetic tape. This profile is due to the non-uniformity in the head-to-tape separation across the tape. In other words, the flying height of the tape varies from point to point across the tape. At points of low flying height, wear of the head is more pronounced than at points of greater flying height.

FIG. **1A** is a schematic illustration of a plain flat magnetic head **20** with the read-write elements **22** located in a flat region **24**, as generally set forth in Hinteregger et al., *Contact Tape Recording with a Flat Head Contour*, IEEE Transactions on Magnetics, Vol. 32, No. 5, Pg. 3476, September 1996. The configuration of FIG. **1A** generates a region of sub-ambient pressure at the interface **26** of the tape **28** moving in the direction **29** and the flat surface **24**. FIG. **1B** is a graphical illustration of the pressure at the interface **26** across the length of the magnetic head **20**. Air is entrained by the tape **28** at the leading edge **30** of the magnetic head **20**, such that the head-to-tape spacing has a slightly diverging shape **32**. Consequently, the air pressure in the region **32** is sub-ambient, as illustrated in FIG. **1B**. The air expands in the region **32** between the tape **28** and the flat region **24** and creates suction under the tape **28**. The air pressure remains generally constant and sub-ambient and the head-to-tape spacing is remains generally constant across the remainder of the flat region **24**.

The highest contact pressure occurs at the leading edge **30** of the magnetic head **20**. With low wrap angles, typically in the range of about 2° and reduced tape tension, the center region **34** of the tape **28** can be subject to instability due to tape flutter. This instability is sensitive to variations in tape speed and tape tension. Instability in the tape **28** in the center region **34** can increase wear on the read-write elements **22** and degrade electrical performance of the magnetic head **20**.

BRIEF SUMMARY OF THE INVENTION

The present negative pressure head contour is less sensitive to tape speed and tape tension while maintaining a substantially uniform tape-to-head spacing over a large flat region on the magnetic head. The downward force needed to maintain the interface between the tape and the present negative pressure head contour is generated primarily by a sub-ambient air bearing and the bending force of the tape, rather than a combination of head penetration and tape tension. The air bearing pressure is sub-ambient across substantially all of the magnetic head, which pulls the tape down to the magnetic head at the interface region. A bending force on the tape created in the cavity adjacent to the read-write elements minimizes instability at the interface, even at high tape speeds. Since the tape tension and head penetration are no longer needed to create the desired head-to-tape spacing, these parameters can be minimized, resulting in reduced head wear and tape damage.

The present invention is directed to a magnetic head assembly in a linear tape system with an interface region having a substantially flat region, a substantially square leading edge and at least one cavity in the flat region. In one embodiment, the cavity has a depth of between about 0.5 micrometers to less than about 20 micrometers. At least one read-write element is located on the flat region adjacent to the cavity. A self-generating sub-ambient condition is cre-

ated by the movement of the tape over the interface region. The magnetic tape is bent or otherwise deformed into the cavity as it passes over the magnetic head assembly, thereby increasing tape stability in the interface region, and therefore, at the interface with the read-write elements.

In another embodiment, the interface region has a substantially flat region with a substantially square leading edge and a pair of cavities in the flat region. The cavity has a depth of between about 0.5 micrometers to less than about 20 micrometers. At least one read-write element is located on the flat region between the pair of cavities, whereby the magnetic tape generates a sub-ambient condition when traversing the interface region, including the cavity. The magnetic tape is deformed as it passes over each of the cavities, thereby increasing tape stability at the interface with the read-write elements.

Magnetic tapes are inherently abrasive and cause wear in the recording heads. Head wear can be severe at high tape speeds if the contour of the head is not properly designed. The present negative pressure head contour provides relatively high contact pressure at the edges of the magnetic head and moderate contact pressure at the read-write elements, where the magnetic performance is influenced the most by wear. Consequently, there is less wear at the read-write elements. Harder materials can be used to reinforce the edges of the magnetic head to maintain head geometry. The hard contact at the edges provides the additional benefit of working as scrapers to reduce the introduction of debris into the read-write gap.

In addition to the low wear characteristics, the present negative pressure head contour provides self-balancing force (upward and downward) at a wide range of tape speeds and tape tensions. This phenomenon reduces the influence of tape speed and tape tension on head-to-tape spacing during all phases of operation, including startup and shut-down. For example, the head-to-tape spacing, contact pressure and Reynolds pressure at the interface with the read-write element is substantially constant at tape speeds of about 4 meters/second to at least 12 meters/second. In another embodiment, the tape maintains asperity contact with the read-write element at tape tensions of less than about 40 Newtons/meter, and preferably less than 20 Newtons/meter at a tape speed of at least about 4 meters/second. Asperity contact refers to at least some light physical contact of the tape on the read-write elements.

The interface between the read-write elements and the tape occurs on the flat region, similar to a rigid disk configuration. A multi-channel head design of the present negative pressure head contour can be constructed using rigid disk head technology. Due to the simplicity of this design, the head can be manufactured easily with tight tolerances on flatness, roughness, and overall geometry. The leading and trailing edges of the magnetic head act as scrapers due to the high contact pressure to minimize the migration of particles into the interface region. Additionally, the cavity adjacent to the read-write elements can serve as a collection point for debris at the interface.

In the illustrated embodiment, the head contour is designed to be symmetrical with respect to the head center line in order to be used for both single direction and bi-directional recording applications. The head contour can be adapted to various tape widths and number of read-write gaps with minor changes.

The present invention is also directed to a magnetic tape system for recording, reproducing and/or erasing magnetic information in a linear tape system or for servo-writing magnetic tapes.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING

FIG. **1A** is a schematic illustration of a prior art flat head contour.

FIG. **1B** illustrates the air pressure under the tape along the head of FIG. **1A**.

FIG. **2A** is a cross sectional view of a negative pressure head contour in accordance with the present invention.

FIG. **2B** illustrates the pressure profile under the tape along the length of the head of FIG. **2A**.

FIG. **3** is a top view of the negative pressure head contour of FIG. **2A**.

FIG. **4** is perspective view of an alternate negative pressure head contour in accordance with the present invention.

FIG. **5A** is a side schematic illustration of an alternate negative pressure head contour in accordance with the present invention.

FIG. **5B** is a perspective view of the alternate negative pressure head contour of FIG. **5A**.

FIG. **6A** is a graphical illustration of contact pressure across the length of a negative pressure head contour in accordance with the present invention.

FIG. **6B** is a graphical illustration of Reynolds pressure across the length of a negative pressure head contour in accordance with the present invention.

FIG. **6C** is a graphical illustration of head-to-tape spacing across the length of a negative pressure head contour in accordance with the present invention.

FIG. **7** is a graphical illustration of the head-to-tape spacing at the read-write gap as a function of tape speed on a negative pressure head contour in accordance with the present invention.

FIG. **8** is a graphical illustration of contact pressure at the read-write gaps as a function of tape speed on a negative pressure head contour in accordance with the present invention.

FIG. **9** is a graphical illustration of the maximum contact pressure at the read-write gaps as a function of tape speed on a negative pressure head contour in accordance with the present invention.

FIG. **10** is a graphical illustration of head-to-tape spacing at the readwrite gap as function of head wrap angle in a negative pressure head contour in accordance with the present invention.

FIG. **11** is a graphical illustration of contact pressure at the read-write gap as a function of head wrap angle in a negative pressure head contour in accordance with the present invention.

FIG. **12** is a graphical illustration of the maximum contact pressure as a function of head wrap angle in a negative pressure head contour in accordance with the present invention.

FIG. **13** is a graphical illustration of the maximum contact pressure as a function of cavity depth in a negative pressure head contour in accordance with the present invention.

FIG. **14A** is a graphical illustration of contact pressure across the length of a negative pressure head contour in accordance with the present invention.

FIG. **14B** is a graphical illustration of Reynolds pressure across the length of a negative pressure head contour in accordance with the present invention.

FIG. **14C** is a graphical illustration of head-to-tape spacing across the length of a negative pressure head contour in accordance with the present invention.

DETAILED DESCRIPTION OF THE INVENTION

FIGS. **2**A and **3** illustrate various views of a magnetic head assembly **50** for recording, reproducing and/or erasing magnetic information in a track of a flexible magnetic tape **52** in accordance with the present invention. The magnetic head assembly includes a first substrate **40** upon which a thin film magnetic read-write element **74** is deposited. A closure piece **44** is bonded to the first substrate. A second substrate **42** with a thin film magnetic read-write element **76** and closure piece **46** is positioned adjacent to the first substrate **40**. The closure pieces **44**, **46** each include raised portions **44**A, **46**A, respectively. The closure pieces **44**, **46** form an open region **45** that permits access to the read-write elements **74**, **76** from behind the magnetic head assembly **50**.

The first substrate **40** includes an outrigger **54**, a bleed slot **70** and a flat region **62**. The second substrate **42** includes an outrigger **58**, a bleed slot **72** and a flat region **64**. The leading edges **84**, **85** of the flat regions **62**, **64**, respectively, are substantially square. In the illustrated embodiment, the flat regions **62**, **64** also include the raised portions **44**A, **46**A of the closure piece **44**, **46**, respectively. The substrates **40**, **42** are bonded with the closure pieces **44**, **46** so that the flat regions **62**, **64** and raised portions **44**A, **46**A form a flat, co-planar surface. The closure pieces **44**, **46** define a cavity **78** that is adjacent to the read-write elements **74**, **76**.

The flat regions **62**, **64**, **44**A, **46**A, the read-write elements **74**, **76** and the cavity **78** define an interface region **81** extending between the edges **84**, **85**. A self-generating sub-ambient condition across the interface region **81** is caused by movement of the tape **52**. The sub-ambient condition causes the tape **52** conforms slightly to the cavity **78** as it traverses the read-write elements **74**, **76**. The slight deformation or bending **94** in the tape **52** provides structural integrity to resist flutter and other instability along the interface region **81** of the magnetic head **56**.

The outriggers **54**, **58** establish a wrap angle **60** of the magnetic tape **52** across the flat regions **62**, **64** of the magnetic head **56**. In order to minimize head penetration into the magnetic tape **52**, the outriggers **54**, **58** preferably maintain a wrap angle in the range of about 1° to about 5°. The surfaces **55**, **59** of outriggers **54**, **58**, respectively, have a radius of about 6 millimeters to about 8 millimeters. The bleed slots are typically at least about 0.1 millimeters (0.004 inches) deep so that air pressure above and below the magnetic tape **52** is substantially at ambient in those regions.

FIG. **2**B is a graphical illustration of the air pressure profile between the magnetic tape **52** and the magnetic head assembly **50**. Due to the depth, length and width of the bleed slots **70** and **72**, the air pressure below the tape **52** is generally at ambient (designated PA) in the regions **80**, **82** respectively. Air entrained at the bottom of the magnetic tape **52** is obstructed at the edge **84** of the flat region **62** (or edge **85** of flat region **64**, depending upon the direction of tape travel since the magnetic head assembly **50** is preferably bi-directional). This phenomenon creates a reduced pressure condition in the region **86** corresponding to the flat region **62**. Since the cavity **78** is relatively shallow, the reduced pressure condition continues through the cavity region **90**. The negative pressure condition is maintained in the flat region **64** corresponding to the region **92**. The self-generating sub-ambient condition is created across the regions **86**, **90**, **92** by movement of the tape. Finally, as the magnetic tape **52** progresses to the bleed slots **72**, an ambient condition is re-established both above and below the tape **52**.

The contact pressure in the cavity region **90** illustrated in FIG. **2**B is generally in the same range as that illustrated in the adjacent flat region **62**, **64**, illustrated as regions **86**, **92**. It is possible that the contact pressure in the cavity region **90** may be slightly greater than or less than that in the adjacent flat regions **62**, **64**, so long as all three regions **86**, **90**, **92** are sub-ambient. The magnitude of the sub-ambient condition must be sufficient to deform or bend the tape **52** as it traverses the cavity **78**. Variations in the contact pressure and the cavity region **90** can be achieved by changing the depth or width of the cavity **78**.

In the illustrated embodiment, each of the flat regions **62**, **64** typically have a length measured in the direction of tape travel of about 0.5 millimeters to about 3 millimeters. The cavity **78** has a length measured in the direction of tape travel of about 0.5 millimeters to about 2 millimeters. The cavity **78** preferably has a depth of at least 0.5 micrometers to about 20 micrometers or less, and more preferably about **0.5** micrometers to about 5 micrometers and most preferably about 0.5 micrometers to about 3 micrometers.

As best illustrated in FIG. **3**, the cavity **78** may have a width **79** measured in a direction perpendicular to the direction of tape travel less than, greater than or equal to the width **53** of the tape **52**. Alternatively, the cavity **78** may have a width **79'** extending across the fill width of the magnetic head assembly **50** (shown in dashed lines). Since the cavity **78** is extremely shallow, the sub-ambient condition is maintained across the interface region **81** even if the cavity **78** has a width less than, greater than or equal to the width **53** of the tape **52**. The read-write elements **74**, **76** typically have a width less than the width **53** of the magnetic tape **52**. The leading edges **84**, **85** of the flat regions **62**, **64**, respectively, are preferably constructed of a extremely hard material, such as Al—TiC (Al_2O_3—TiC). The flat regions **62**, **64** preferably have a flatness of less than about 100 nanometers and a surface roughness of less than about 100 nanometers RMS. The entire interface region **81** preferably has a flatness of less than about 100 nanometers.

FIG. **4** is a perspective schematic illustration of the magnetic head assembly **50** of FIG. **3** without the various layers illustrated. The cavity **78** may alternately extend to the edge of the magnetic head assembly **50**, as shown in FIG. **3**.

FIG. **5**A is a schematic illustration of an alternate magnetic head assembly **100** in accordance with the present invention. The magnetic head assembly **100** includes a pair of substrates **130**, **132** upon which are deposited read-write elements **104**, **106**. Closure pieces **134**, **136** form an interface between the substrates **130**, **132**. The substrates **130**, **132** include a flat regions **114**, **116** adjacent to cavities **110**, **112**, respectively. Flat regions **113**, **115** are located on the substrates **130**, **132** on the opposite side of the cavities **110**, **112**, respectively. The closure pieces **134**, **136** define a portion of a flat region **108** located between the read-write elements **104**, **106**. The flat regions **108**, **113**, **114**, **115**, **116** are preferably co-planar. Flat regions **114**, **116** are adjacent to bleed slots **118**, **120**, respectively. Outriggers **138**, **140** are located beyond the bleed slots **118**, **120**, respectively.

FIG. **5**B is a perspective schematic illustration of the alternate magnetic head assembly **100** of FIG. **5**A, without the various layers illustrated. Although the cavities **110**, **112** extend to the edge of the magnetic head assembly **100**, they may alternately terminate before the edge, as illustrated in FIG. **4**.

In the embodiment illustrated in FIG. **5**A, interface region **126** extends between edges **122** and **124** of the magnetic head assembly **100**. The sub-ambient condition extends substantially across the interface region **126**. As discussed in

connection with FIG. **2A**, the contact pressure profile in the cavity regions **110**, **112** can be adjusted by adjusting the depth, width and length of the cavities. The embodiment illustrated in FIG. **5A** has the advantage that the separation between the read-write elements **104**, **106** can be adjusted, and preferably minimized, while still maintaining an adequate length for the cavities **110**, **112**, as measured along the direction of tape travel.

EXAMPLE 1

The design of the negative pressure head contour in accordance with the present invention is based upon two and three dimensional computer simulations of the head-to-tape interface. The simulation involves the numerical solutions to Reynolds equations coupled with the tape elastic equation. The results presented below are based on the elastic and surface properties of 18 gauge magnetic recording medium available in a number of Imation Corporation products, such as the Travan data cartridge. The simulated results for the head-to-tape interface were verified using a glass head with the geometry discussed below and monochromatic interferometry techniques. Interferometry can also be used to evaluate whether a particular magnetic head assembly maintains asperity contact at various pressures, tape tensions, tape speeds, etc.

The results of two dimensional simulations are for tape 7.5 micrometers thick at a tape tension of about 87.56 Newtons/meter (2 ounces per quarter of inch) and a tape speed of about 5.08 meters per second (200 inches per second). A wrap angle of about 1° with respect to the outriggers and a cavity about 1 micrometer deep were used in the simulations. The flat regions and the cavity had a length measured in the direction of tape travel of about 2 millimeters. The head-to-tape spacing was about 35 nanometers and the Reynolds pressure was sub-ambient over a large portion of the head, except in the transition zones. The negative pressure head contour was generally as illustrated in FIGS. **2A**, **3** and **4**.

FIG. **6A** illustrates the contact pressure as a function of relative distance across the magnetic head. The horizontal axis illustrates the relative distance in the direction of the tape travel in millimeters. Tape travel is from left to right. The center, designated 0.0, is the center of the cavity. The cavity extends about 1.0 millimeter on either side of the center. The flat regions extend for about 2.0 millimeters on both sides of the cavity. The vertical axis is the contact pressure in atmospheres. The maximum contact pressure occurs in the transition zones at the leading and trailing edges of the cavity, designated −1.0 and 1.0, respectively, because the tape bends into the cavity. The maximum contact pressure also occurs at the transition zones at the outside edges of the flat regions, designated −3.0, 3.0, next to the bleed slots. The contact pressure is relatively uniform elsewhere, and especially along the flat regions containing the read-write elements.

FIG. **6B** illustrates the Reynolds pressure as a function of relative distance across the magnetic head. The horizontal axis is the same as in FIG. **6A**. Again, the maximum Reynolds pressure occurs at the leading and trailing edges of the two flat regions, designated −3.0, −1.0 and 1.0, 3.0, respectively.

FIG. **6C** illustrates the head-to-tape spacing as a function of relative distance across the magnetic head. The horizontal axis is the same as in FIG. **6A**. The vertical axis is the cavity depth in 10^{-7} meters. The maximum head-to-tape spacing occurs at the leading and trailing edges of the cavity, designated −1.0 and 1.0, respectively.

In order to assure a proper mechanical operation of the head in a tape drive, the analysis takes into consideration ranges of tape tension and tape speed. A typical tape tension of about 20 to about 100 Newtons per meter is considered for a tape speed of about 1 to about 10 meters per second. As illustrated in FIG. **7**, the head-to-tape spacing at the read-write gap decreases with decreasing tape tension. Head-to-tape spacing decreases as tape speed increases after a tape speed of about **4** meters/second is achieved. The head-to-tape spacing at the read-write gap is less sensitive to tape speed of at least 12 meters/second.

As illustrated in FIG. **8**, the contact pressure, normalized to atmospheric pressure, at the read-write element increases with tape tension. Contact pressure at the read-write element also increases as tape speed increases. After a tape speed of about 4 meters/second is achieved, contact pressure at the read-write element is less sensitive to tape speed, to tape speeds of at least 12 meters/second.

As illustrated in FIG. **9**, maximum contact pressure increases with tape tension. However, as with head-to-tape spacing and contact pressure at the read-write element, the maximum contact pressure increases with tape speed until a tape speed of about 4 meters/second is achieved. Thereafter, maximum contact pressure is less sensitive to tape speed, even at tape speeds of at least 12 meters/second. Head-to-tape spacing at the read-write element, contact pressure at the read-write element, and maximum contact pressure stabilize at a tape speed of about 4 meters per second and are generally uniform at tapes speeds of at least 12 meters/second.

FIGS. **10–12** illustrate the effect of wrap angle on head-to-tape spacing at the read-write element, contact pressure at the read-write element, and maximum contact pressure, respectively. As discussed above, the cavity depth was about **1** micrometer, the tape speed was about 5.08 meters/second and the tape tension was about 87.56 Newtons/meter. The head-to-tape spacing becomes smaller while the contact pressure and maximum contact pressure becomes slightly larger as wrap angle increases. Wrap angles beyond about 5° do not substantially improve the head-to-tape spacing, but increases the maximum contact pressure and head wear. It appears that wrap angle between about 0.5° to about 5° provides the optimal performance.

The effective cavity depth on maximum contact pressure at a wrap angle of about 1°, a tape speed of about 5.08 meters/second and a tape tension of about 87.56 Newtons/meter is shown in FIG. **13**. In spite of the initial rise in maximum contact pressure as a function of cavity depth, the head-to-tape spacing and the contact pressure at the element do not change substantially over a range of cavity depths of about 1 to about 5 micrometers. However, for a much deeper cavity (greater than about 10 micrometers), the overall contact pressure is reduced in the head-to-tape spacing at the read-write element becomes larger. As the cavity depth increases to about 30 micrometers, the cavity operates more like a bleed slot and the advantages of the sub-ambient condition at the read-write element are lost.

EXAMPLE 2

Example 2 relates to a design of the negative pressure head contour in accordance with the two-cavity embodiment illustrated in FIG. **5A**. The data is based upon computer simulations of the head-to-tape interface. The simulation involves the numerical solutions to Reynolds equations coupled with the tape elastic equation. The results presented below are based on the elastic and surface properties of 18

gauge magnetic recording medium available in a number of Imation Corporation products, such as the Travan data cartridge.

The results of two dimensional simulations are for tape 7.5 micrometers thick at a tape tension of about 87.56 Newtons/meter (2 ounces per quarter of inch) and a tape speed of about 5.08 meters per second (200 inches per second). A wrap angle of about 1° with respect to the outriggers and a about 1.0 micrometer deep cavity were used in the simulations. The center flat region and the two cavities each had a length measured in the direction of tape travel of about 1 millimeters. The flat regions on the outside of the two cavities each had a length of about 0.5 millimeters. The head-to-tape spacing was about 43 nanometers and the Reynolds pressure was sub-ambient over a large portion of the head, except transition zones.

FIG. **14**A illustrates the contact pressure as a function of relative distance across the magnetic head. The horizontal axis illustrates the relative distance in the direction of the tape travel in millimeters. Tape travel is from left to right. The center, designated 0.0, is the center of the flat region containing the read-write elements. The flat region extends 0.4 millimeters on either side of the center. The cavities extend for 0.8 millimeter on both sides of the center flat region. The cavities are located at about −12.0, −4.0 and 4.0, 12.0, respectively, along the horizontal axis. The flat regions on the outside of the cavities are located at about −16.0, −12.0 and 12.0, 16.0, respectively.

The vertical axis is the contact pressure in atmospheres. The maximum contact pressure occurs at the transition zones at the leading and trailing edges of the cavities, designated −12.0, −4.0, 4.0, 12.0, respectively, because the tape bends into the cavities. The maximum contact pressure also occurs at the outside edges of the flat regions, designated −16.0, 16.0, adjacent to the bleed slots. The contact pressure is relatively uniform elsewhere, and especially along the flat regions containing the read-write elements.

FIG. **14**B illustrates the Reynolds pressure as a function of relative distance across the magnetic head. The horizontal axis is the same as in FIG. **14**A. The maximum Reynolds pressure occurs at the same locations as the maximum contact pressure.

FIG. **14**C illustrates the head-to-tape spacing as a function of relative distance across the magnetic head. The horizontal axis is the same as in FIG. **14**A. The vertical axis is the cavity depth in 10^{7} $^{-}$meters. The maximum head-to-tape spacing occurs at the same locations as the maximum contact pressure and maximum Reynolds pressure.

The complete disclosures of all patents, patent applications, and publications are incorporated herein by reference as if individually incorporated. Various modifications and alterations of this invention will become apparent to those skilled in the art without departing from the scope and spirit of this invention, and it should be understood that this invention is not to be unduly limited to the illustrative embodiments set forth herein.

What is claimed is:

1. A magnetic head assembly in a linear tape system, comprising:

an interface region having a substantially flat region with a substantially square leading edge and at least one cavity in the flat region, the cavity having a depth of between about 0.5 micrometers and about 20 micrometers; and

at least one read-write element located on the flat region adjacent to the cavity, whereby movement of a magnetic tape traversing the interface region generates a sub-ambient condition substantially across the interface region and is deformed as it passes over the cavity, thereby increasing tape stability at an interface with the read-write element.

2. The magnetic head assembly of claim **1** comprising a pair of bleed slots adjacent to the interface region.

3. The magnetic head assembly of claim **2** comprising a pair of outrigger positioned adjacent to the bleed slots for maintaining a wrap angle of less than about 5 degrees between a magnetic tape and the interface region.

4. The magnetic head assembly of claim **1** comprising at least one outrigger positioned to maintain a wrap angle of less than about 5 degrees between a magnetic tape and the magnetic head.

5. The magnetic head assembly of claim **1** further comprising a read-write element adjacent to each side of the cavity.

6. The magnetic head assembly of claim **1** comprising a pair of cavities in the flat region.

7. The magnetic head assembly of claim **6** wherein the read-write element is located on the flat region between the pair of cavities.

8. The magnetic head assembly of claim **1** wherein the leading edge comprises a material with a greater resistance to wear than the read-write elements.

9. The magnetic head assembly of claim **1** wherein the interface region comprises a flatness of less than about 100 nanometers.

10. The magnetic head assembly of claim **1** wherein the cavity comprises a length measured in a direction of tape travel of less than about 2.0 millimeters.

11. The magnetic head assembly of claim **1** wherein the flat region comprises a length measured in a direction of tape travel of less than about 2.0 millimeters.

12. The magnetic head assembly of claim **1** wherein the cavity comprises a width measured in a direction perpendicular to a direction of tape travel less than, greater than or equal to a width of a magnetic tape.

13. The magnetic head assembly of claim **1** wherein the sub-ambient condition comprises a Reynolds pressure of less than about 1 atmosphere.

14. The magnetic head assembly of claim **1** wherein the magnetic head assembly is capable of recording, reproducing and/or erasing magnetic information in the linear tape system bi-directionally.

15. The magnetic head assembly of claim **1** comprising a servo-writing magnetic head assembly.

16. The magnetic head assembly of claim **1** wherein the cavity comprises a depth of between about 0.5 micrometers and about 10 micrometers.

17. A magnetic head assembly for recording, reproducing and/or erasing magnetic information on a magnetic tape in a linear tape system, the magnetic head assembly comprising:

an interface region having a substantially flat region with a substantially square leading edge and at least one cavity in the flat region, the cavity having a depth of between about 0.5 micrometers and about 20 micrometers;

a pair of bleed slots located adjacent to the interface region;

a pair of outriggers for maintaining a wrap angle of less than about 5 degrees between a magnetic tape and the interface region; and

at least one read-write element located on the flat region adjacent to the cavity, whereby movement of the mag-

netic tape generates a sub-ambient condition at the interface region.

18. A magnetic tape system for recording, reproducing and/or erasing magnetic information in a linear tape system, the magnetic tape system comprising:

a magnetic tape;

a magnetic head assembly comprising;

an interface region having a substantially flat region with a substantially square leading edge and at least one cavity in the flat region, the cavity having a depth of between about 0.5 micrometers and about 20 micrometers; and

at least one read-write element located on the flat region adjacent to the cavity, whereby the magnetic tape traversing the interface region generates a sub-ambient condition and is deformed as it passes over the cavity, thereby increasing tape stability at an interface with the read-write element.

19. The magnetic tape system of claim **18** wherein a head-to-tape spacing at the interface with the read-write element is substantially constant at tape speeds of about 4 meters/second to at least about 12 meters/second.

20. The magnetic tape system of claim **18** wherein contact pressure of the tape at the interface with the read-write element is substantially constant at tape speeds of about 4 meters/second to at least about 12 meters/second.

21. The magnetic tape system of claim **18** wherein Reynolds pressure of the tape at the interface with the read-write element is substantially constant at tape speeds of about 4 meters/second to at least about 12 meters/second.

22. The magnetic tape system of claim **18** wherein the tape has a thickness of less than about 15 micrometers.

23. The magnetic tape system of claim **18** wherein the tape maintains asperity contact with the read-write element at tape tensions of less than about 40 Newtons/meter.

24. The magnetic tape system of claim **18** wherein the tape maintains asperity contact with the read-write element at tape tensions of less than about 40 Newtons/meter at a tape speed of at least about 4 meters/second.

25. The magnetic tape system of claim **18** wherein the tape maintains asperity contact with the read-write element at tape tensions of less than about 20 Newtons/meter at a tape speed of at least about 4 meters/second.

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